Marine Policy 101 (2019) 177–186

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Small-scale fisheries in Canada's Arctic: Combining science and fishers knowledge towards sustainable management

Marie-Julie Roux[a,*], Ross F. Tallman[b], Zoya A. Martin[c]

[a] National Institute of Water and Atmospheric Research (NIWA), 301 Evans Bay Parade, Greta Point, Wellington 6021, New Zealand
[b] Government of Canada Department of Fisheries and Oceans, 501 University Crescent, Winnipeg, MB, Canada R3T 2N6
[c] Government of Canada Department of Fisheries and Oceans, P.O. Box 358, Iqaluit, NU, Canada X0A 0H0

ARTICLE INFO

Keywords:
Small-scale fisheries
Traditional ecological knowledge (TEK)
Stock assessment
Productivity-susceptibility analysis (PSA)
Arctic char
Data poor fisheries management

ABSTRACT

In remote and data-limited situations such as encountered in Arctic regions, traditional ecological knowledge (TEK) is an important and valuable information source. TEK from local fishers (fishers knowledge, FK) is highly relevant to fisheries management. The integration of FK in fisheries assessments remains complicated by the lack of tools to combine scientific and FK observations. This study implements a productivity-susceptibility analysis (PSA) for assessing the risk from fishing to fish stocks and incorporate FK in the assessment process. The PSA method consists of scoring productivity attributes of fish populations and susceptibility attributes affecting fisheries exposure and intensity. The method can be adapted to incorporate FK on two levels: (1) in the validation of biological data (indirect inclusion); and (2) in the definition and scoring of independent FK attributes (direct inclusion). Risk scores measured along the productivity-susceptibility gradient serve to identify areas and populations most vulnerable to fishing activities and formulate science advice for prioritisation and management. We apply the method to small-scale fisheries for Arctic char *Salvelinus alpinus* in Cumberland Sound, Baffin Island, Nunavut. These fisheries are key to food security and economic growth in Canada's Arctic territories, yet management remains complicated by data paucity; by the widespread distribution and biological complexity of Arctic char stocks; and by growing uncertainties related to climate change impacts on Arctic fish and ecosystems. This paper demonstrates the usefulness of the method for combining science and FK information to improve management advice for Arctic char stocks, and applicability to other small-scale, data-limited fisheries.

1. Introduction

Traditional ecological knowledge (TEK) has extensive value for developing sustainable resource use and conservation strategies [1–5]. This is especially true in remote Arctic regions, where TEK is often the most abundant and valuable information source. Small-scale fisheries for Arctic char *Salvelinus alpinus* are key to food security and economic growth in Canada's Arctic communities, yet their assessment and management remains complicated by data and accessibility constraints. Inuit fishers have detailed knowledge of Arctic char resources and their environments. This knowledge is readily available, generally exceeds the available scientific data in sample sizes and recurrence of observations, and requires to be integrated in stock assessments and management practice to ensure sustainable resource use and conservation.

Arctic peoples depend on ecosystem services for their subsistence and livelihoods, and maintain a detailed knowledge of natural resources and their environments. TEK in Arctic regions is implemented in various life sustaining activities and its validation has been based on the persistence of both people and culture in harsh Arctic environments [6,7]. In Canada's Arctic territories, the incorporation of TEK in environmental assessments and natural resources management is a policy requirement established by treaty or land settlement agreement and implemented in shared-management frameworks and responsibility between government, resource users, local communities and aboriginal groups [1,8,9]. As a result, TEK integration mainly occurs via representation by “bridging” organisations in the context of participatory, collaborative frameworks [10,11]. Direct integration remains marginal. Examples of studies that have engaged both TEK and science to understand aspects of Arctic ecosystems and environmental change include assessments of polar bear [6], migratory seabirds [12,13], fish [14] and marine mammals populations [2,15–19] – looking at seasonal movements, distribution, habitat preferences, abundance trends and/or incidence of disease. Other examples include the evaluation of long-term changes in snow and ice conditions as related to reindeer herding practice [20], and changes in local weather patterns [21]. In all cases,

* Corresponding author. Present address: Government of Canada Department of Fisheries and Oceans, 850 Route de la Mer, Mont-Joli, QC, Canada G5H 3Z4.
E-mail addresses: Marie-Julie.Roux@dfo-mpo.gc.ca (M.-J. Roux), ross.tallman@dfo-mpo.gc.ca (R.F. Tallman), zoya.martin@dfo-mpo.gc.ca (Z.A. Martin).

https://doi.org/10.1016/j.marpol.2018.01.016
Received 24 November 2016; Accepted 16 January 2018
Available online 07 February 2018

qualitative TEK information was used to corroborate or invalidate empirical data and trends derived from independent scientific surveys (with a focus on describing similarities and differences between the two types of information); or to broaden research outcomes by introducing scientists to alternative perspectives. To our knowledge, practical examples of TEK inclusion in the science frameworks and quantitative tools used to inform species and environmental management decisions, are still lacking.

TEK and scientific data provide independent sources of information that can be combined to increase confidence and depth of knowledge [22]. Like scientific knowledge, TEK consists of evidential (empirical) observations and experimental information (i.e., interpretations of observations through testing and validation or refutation) [4,6,8]. Scientific knowledge is held to be neutral and objective (even despite increasing advocacy and potentially related bias), while TEK is framed within the cultural context that developed and holds it [6]. For this reason, TEK is commonly described (and erroneously dismissed) as anecdotal and subjective [3,4]. Combining the two forms of knowledge is feasible and highly desirable, but requires a clear definition of TEK relative to the study aims [23], and the identification of TEK components compatible with scientific process (i.e., the distinction between knowledge that has an empirical basis, versus knowledge potentially substantiating artefacts, and knowledge beyond time and space linked to identity, values, ethics, worldviews and philosophy [8,11]).

In this paper, we focus on fishers knowledge (FK) defined as the TEK held by Inuit fishers, which "has evolved through adaptive processes and has been handed down through generations" [24]. In this context, FK consists of factual, empirical and pragmatic (experience-based) observations on the biology and ecology of fish species, populations and ecosystems, as well as past and present exploitation patterns and management. This definition includes TEK categories 1 and 2 as proposed by Usher [1], but is exclusive of beliefs and values about fisheries and the environment and the knowledge system used to define them (Usher [1] TEK categories 3 and 4). In fisheries science, this type of FK information is increasingly recognized as an important class of knowledge that has yet to become successfully integrated within scientific practice [5,25,26].

Anadromous Arctic char is an abundant and predictable food source in Arctic environments, with historical and present-day cultural and economic importance to circumpolar Arctic peoples [27,28]. In Canada's Nunavut Territory, Arctic char populations are subject to non-negligible levels of subsistence harvest [29] and increasing opportunities for commercial fisheries development [30]. Emerging commercial fisheries allow for economic expansion in Inuit communities while sustaining traditional cultural ties to land- and harvest-based activities. Fisheries assessment and management processes to ensure sustainability however, remain complicated by several factors. These include (1) incomplete harvest statistics (mainly due to subsistence harvests being unreported); (2) problems of scale (owing to the larger number, widespread distribution and biological complexity of Arctic char stocks); and (3) growing uncertainties related to climate change impacts on Arctic fish and ecosystems. For these reasons, conventional approaches relying on estimates of population abundance and the setting of harvest levels are often impractical, both in terms of feasibility and applicability. Alternative risk assessment methods such as the productivity-susceptibility analysis (PSA) can provide useful tools to inform management decisions [30].

The PSA evaluates risk to a species or population as a function of its productivity (as this determines resilience and recovery potential) and susceptibility (as this determines exposure and the relative intensity of a threat). The method has been developed and applied to evaluate the risk from commercial fisheries to numerous and diverse bycatch species and targeted fish stocks [31–38]. Multi-species PSAs serve to rank species relative to one another and prioritise high risk species for management. Roux et al. [30] developed and applied a single-species PSA to 86 anadromous Arctic Char stocks from across Nunavut. Sufficient contrast in life history traits was available to differentiate stocks productivity. The method was useful for distinguishing between fishery areas having higher and lower risk (on a broad spatial scale) and between higher and lower risk stocks at the regional scale. Preliminary outputs however, were limited by incomplete and/or outdated biological information and a set of proxies for susceptibility attributes unlikely to capture the full complexity/adequately index fishery exposure and intensity. One way to refine PSA assessments of Arctic Char stocks is via the inclusion of FK information.

To this day, failure to incorporate FK data in fisheries assessment and management systems is in part due to inertia in favour of established scientific paradigms [2], but mainly also because the tools and guidance required to effectively combine FK and scientific data are still lacking [5,8,25]. In data-limited situations, the PSA method provides a flexible framework for data synthesis and integration that can incorporate region-specific information on fishery and management activity [34]. In this paper, we demonstrate how the PSA framework can also be used to combine FK and scientific knowledge in the evaluation of risk from commercial and subsistence fisheries to targeted fish populations.

We implement PSAs with FK in a case study of small-scale Arctic char fisheries from the Cumberland Sound Area, Baffin Island, Nunavut Territory, Canada. The PSA framework is used to directly incorporate FK data in the definition and scoring of a set of FK susceptibility attributes; and indirectly via the validation and weighing of productivity attributes based on correspondence between FK and scientific observations. A scenario-based approach is used to compare outcomes between PSA assessments performed with and without the inclusion of FK. The aims of this paper are to (1) demonstrate the value of the PSA method for incorporating FK in the assessment and management of a fishery resource; (2) evaluate and compare risk outcomes between science-based and combined science/FK assessments in small-scale fisheries; and (3) formulate recommendations for application in other data-limited, small-scale fisheries.

2. Methods

2.1. Case study area

Cumberland Sound is a large inlet approximately 300 km long and 65 km wide (on average), located in southeast Baffin Island, Nunavut Territory, Canada (Fig. 1). The Sound opens into Davis Strait and the Labrador Sea and is a rich habitat for marine mammals influenced by both Arctic (i.e. Baffin Island Current) and Atlantic (i.e., Greenland Current) water masses [39]. Its shoreline consists of several, deeply indented fjords and numerous river/lake systems that provide abundant habitat for Arctic char. Residents of Pangnirtung (population 1400), the only Inuit hamlet in Cumberland Sound, have a long tradition of traveling the fjords, following the migration of marine mammals, caribou and fish, and the making and breaking of the huge ice sheets that offer highways across the Sound [40]. Arctic char is the main food fish for the community, and was traditionally caught using stone weirs during the August migration from salt to freshwater, and in inland lakes during winter. Anadromous Arctic char spawn and overwinter in freshwater lakes and migrate to marine environments every summer for feeding. Details on the biology and ecology of Arctic char in the Canadian Arctic are available from Johnson 1980 [41]. Commercial fishing for Arctic char began in the early 1990s with the opening of *Pangnirtung fisheries Ltd.,* the community-owned and operated fish processing plant established in 1992. Nowadays, both subsistence and commercial fisheries for Arctic char are conducted using 140 mm mesh nylon gillnets set in fjords, coastal areas or near river mouths in late summer and under the ice in freshwater lakes during winter. Fisheries management for anadromous Arctic char in Nunavut follows a waterbody-by-waterbody strategy, whereby fish overwintering in headwater lake(s) of a given river/fjord system are assumed to represent a distinct biological stock.

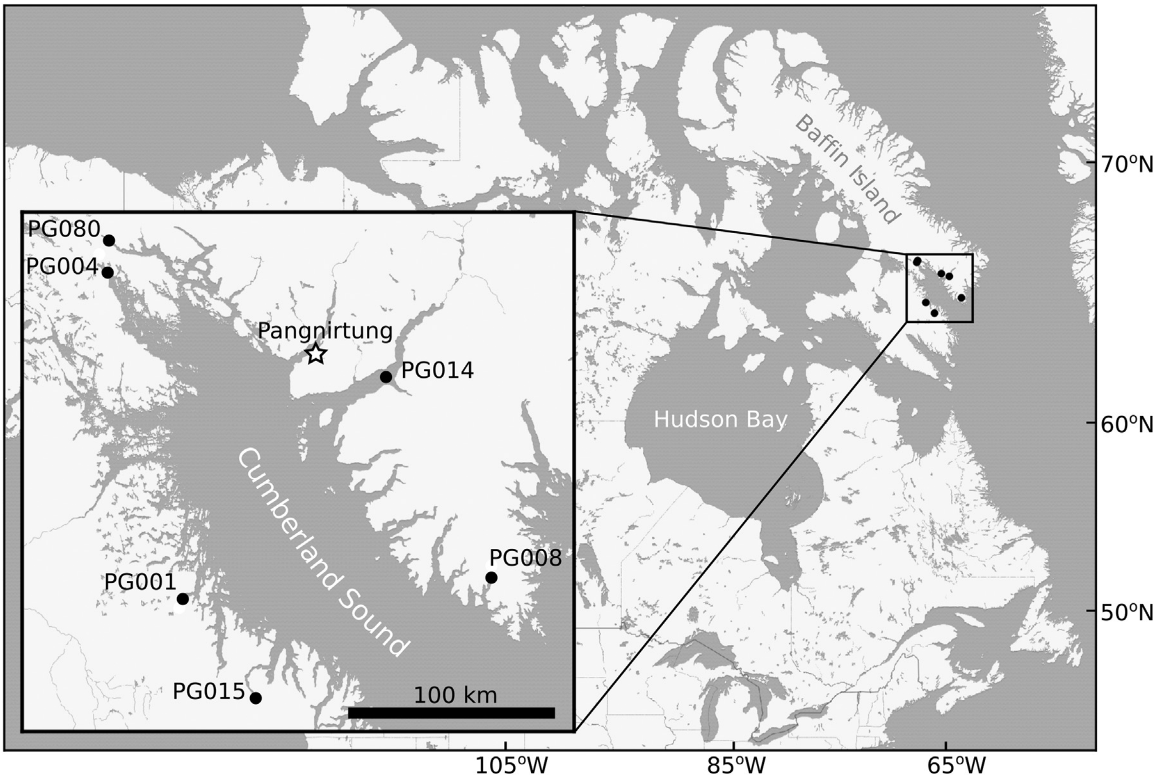

Fig. 1. Map of the Cumberland Sound Area, Baffin Island, Nunavut Territory, Canada, showing the emplacement of Pangnirtung hamlet and the location of six Arctic char stocks/waterbodies considered for assessment: Iqaluit (PG001); Isuituq (PG080); Kingnait (PG014); Kipisa (PG004); Nauliniavik (PG008) and Qasigiyat (PG015).

In the Cumberland Sound Area, the provision of commercial and exploratory fishing licences (i.e. test fisheries pending commercial licensing) for individual waterbodies, has been paralleled by research initiatives to collect fisheries independent data since the late 1990s, and more recently by the development and testing of a community-based fishery monitoring programme in 2012–2014. Our case study focuses on six (6) Arctic char stocks from the Cumberland Sound Area that are fished both commercially and for subsistence purposes and for which standardised, fisheries independent data were available for the period 2000–2006: Iqaluit (PG001); Kipisa (PG004); Nauliniavik (PG008); Kingnait (PG014); Qasigiyat (PG015); and Isuituq (PG080) (Fig. 1).

2.2. FK data collection

An interview questionnaire was prepared along with a set of maps of selected commercial or exploratory waterbodies in the Cumberland Sound Area. The questionnaire contained a personal information section and a total of 6 scoring questions. In the personal information section, fishers were asked to describe their experience with Arctic char fisheries (both commercial and subsistence), in general and by waterbody, and to coarsely identify preferred fishing locations on the maps (e.g., lake, river, fjord or coastal area). In scoring questions, fishers were asked to score waterbodies (on a scale of 1–3) for (1) seasonal quality of fishing; (2) fish size; (3) relative abundance of red fish (current year spawners); (4) present and historical levels of subsistence harvest; (5) fishery desirability; and (6) overall effort required to catch fish. All questions included a section for comments in which fishers were invited to contribute complementary or additional information they considered relevant. Some of the scoring questions also included a subsection asking fishers to describe changes over time, if any (e.g., changes in fish size and desirability). Questionnaires were available in both English and Inuktituk and were completed in semi-directed interviews guided by one or more fisheries biologists, with the assistance of a translator. This method was found to be both effective and powerful for accurate and comprehensive TEK documentation [42]. Invitations to participate in semi-directed interviews and the collection of FK data on Arctic char stocks were extended to all community fishers via the Pangnirtung Hunters and Trappers Association (HTA). In total, 16 fishers were interviewed and/or completed the questionnaire between December 2011 and February 2016 (Table 1). There was one case in which the fisher completed the questionnaire on his own. Owing to the important time lag in completing FK data acquisition, answers to sub-questions about temporal changes in the fisheries were not considered in the present study. Similarly, additional information provided in the comments sections were compiled into a database and retained for future reference and analyses.

2.3. Productivity susceptibility analyses (PSA)

The productivity-susceptibility analysis consists of scoring a set of productivity and susceptibility attributes on an ordinal scale from 1 to 3. Risk (R) is measured along the productivity-susceptibility gradient and quantified as the Euclidean distance from the origin on a two-dimensional productivity-susceptibility plot:

$$R = \sqrt{(P-3)^2 + S+1^2}$$

Where P and S represent productivity and susceptibility scores, respectively. Productivity attributes are estimated based on the available biological (life history traits) data. Standard susceptibility attributes include availability (overlap between fishing effort and stock distribution), encounterability (likelihood that the stock will encounter fishing gear within its range) and selectivity (capture and retention potential of the fishing gear). All analyses (i.e., PSA assessments including the estimation of productivity and susceptibility attributes) were performed in R software (R Core Team 2016).

2.3.1. Productivity attributes

Five productivity attributes were considered for analysis: maximum

Table 1
Fishers knowledge (FK) sample characteristics, including gender (M = male), occupation, years of experience, whether the respondent is engaged in commercial (as well as subsistence) fishing activities (Y = yes), and interview date. HTA = Hunters and Trappers Association. The term 'Harvester' is used to describe the practice of a range of land-based activities (e.g., hunting, trapping, etc.), generally for subsistence purposes.

Respondent	Gender	Occupation	Experience (years)	Commercial fisher	Date interviewed
1	M	Hunter and HTA Board Member	20	Y	Dec-11
2	M	Fisher/Harvester	50	Y	Dec-11
3	M	HTA Board Member	5	Y	Dec-11
4	M	Fisher	11	Y	Dec-11
5	M	Fisher/Harvester	60	Y	Dec-11
6	M	Fisher/Harvester	40	Y	Dec-12
7	M	Fisher/Harvester	40	Y	Dec-12
8	M	Hunter	12	Y	Dec-12
9	M	Fisher/Harvester	30	Y	Dec-12
10	M	Fisher/Harvester	40	Y	Feb-16
11	M	Fisher (helper)	4	Y	Feb-16
12	M	Fisher/Harvester	20	Y	Feb-16
13	M	Fisher/Harvester	10	Y	Feb-16
14	M	Fisher	20	Y	Feb-16
15	M	Fisher	30	Y	Feb-16
16	M	Fisher (helper)	2	Y	Feb-16

Table 2
Productivity attributes and scoring thresholds used in productivity-susceptibility analysis. Productivity tiers are based on data from 86 anadromous Arctic char stocks from Nunavut Territory, Canada [30].

Productivity attributes	Description	Productivity tiers and scores		
		Low (1)	Moderate (2)	High (3)
L_{MAX}	Maximum length (mm (fork length))	848–913	739–847	664–738
A_{MAX}	Maximum age (years)	22–28	15–21	Nov-14
L_{A10}	Mean length at Age 10 (mm (fork length))	426–517	518–648	649–711
$A_{RECRUIT}$	Modal age (years)	15–20	Oct-14	6-Sep
Z	Instantaneous mortality (estimated from catch curve analysis)	0.19–0.30	0.31–0.73	0.74–1.08

length (L_{MAX}), maximum age (A_{MAX}), mean length at age 10 (L_{A10}), age of full recruitment to the fishery ($A_{RECRUIT}$) and instantaneous mortality (Z) (Table 2). Productivity attributes were estimated for each stock using fisheries-independent biological data collected in experimental surveys between 2000 and 2006 by fisheries biologists in collaboration with community co-researchers. Sampling was conducted using gill nets (experimental multi-mesh (38–102 mm) and commercial 140 mm stretched mesh). During these surveys, fish were sampled for length (fork length (mm)), body and gonad mass (g), sex, reproductive status, and sagittal otoliths for age determination. Fish were aged in the laboratory using otolith sections (see Loewen et al. [43] for full description of the aging method).

All attributes but $A_{RECRUIT}$ were estimated using the pooled sample from all gear types. $A_{RECRUIT}$ was determined as the modal age in the commercial gear (140 mm mesh gill net) sample. L_{MAX} and A_{MAX} were calculated as the mean length and age of the ten largest and oldest fish, respectively. L_{A10} is the mean length of fish in the year 10 age group. Z was estimated from age frequency data using catch curve analysis (ln (numbers) versus age in linear regressions fitted to fully recruited age groups starting with the age of full recruitment + 1 year). According to life history theory [44], L_{MAX}, A_{MAX} and $A_{RECRUIT}$ are negatively correlated to population productivity (i.e., populations that reach larger sizes, have longer lifespans and grow slower (and therefore recruit to the fishery at an older age) are generally less productive). In contrast, L_{A10} and Z are positively related to productivity (i.e., faster growth and higher mortality rates are both characteristics of highly productive populations). Productivity scoring thresholds were based on the range of values observed across 86 anadromous Arctic char stocks from throughout the Nunavut Territory [30]. These values are assumed to represent the credible range of life history diversity exhibited by Arctic char populations in the Canadian Arctic. Observed ranges were split into tiers with the lower limit of the lowest productivity tier and the higher limit of the highest productivity tier corresponding to mean values ± standard deviations (Table 2). A data quality index was defined for productivity attributes based on samples sizes and the number of sampling years. For each stock, each productivity attribute was given a data quality score on a scale of 1–5, with 1 corresponding to higher data quality (Table 3). Data quality scores were used to characterise and distinguish uncertainty in the available (experimental) dataset among stocks.

2.3.2. *Susceptibility attributes*

Susceptibility attributes were scored on a scale of 1–3, however with intermediate values in the case of availability and encounterability (e.g., 1.2, 1.3. 1.5, 2.5). Susceptibility attributes for Arctic char were estimated and scored based on availability, encounterability and selectivity proxies proposed by Roux et al. [30]. Availability was positively related to susceptibility and approximated based on the overlap between fishing location and habitat type. This approach assumes that the overlap between fishing effort and Arctic char incidence is highest at river mouths during downstream (early-summer) or upstream (autumn) migrations; intermediate in lakes and fjords; and lowest in coastal environments where fish disperse throughout the summer (Table 4). Encounterability for a stock was approximated based on its location (straight line distance in km) relative to the nearest community (in this case, Pangnirtung). Encounterability decreased with increasing distance from the community. Selectivity was defined as the ratio of average length in the population sample to the commercial mesh size

Table 3
Data quality score for productivity attributes, as defined based on samples size and number of sampling years in the experimental dataset (2000–2006).

Data quality score	Description
1	**Best available data:** sample size > 300 fish, 3 or more sampling years.
2	**Good data:** sample size > 300 fish, 2 sampling years.
3	**Adequate data:** sample size < 300 but > 200 fish, 2 or more sampling years.
4	**Limited data:** sample size < 200 but > 100 fish, single year sample.
5	**Very limited data:** sample size < 100 fish.

Table 4
Standard susceptibility attributes and scoring thresholds used in productivity-susceptibility analysis.

Susceptibility attributes	Description	Low (1)	Moderate (2)	High (3)	Note
Availability	Overlap between fishing activities and habitat type (as a surrogate for species incidence and distribution)	Ocean (coastal areas)	Lakes and Fjords (or coastal areas and river mouth combination)	River mouth	Intermediate scores = 2.5 (for lake/fjord and river mouth combinations); and 1.5 (for coastal and fjord/lake combinations)
Encounterability	Straight line distance from nearest community (km)	> 200	100–110	< 10	Intermediate scores = from 1.1 to 2.9 (with 0.1 increment at each 10 km distance interval).
Selectivity	Ratio of mean length (mm (fork length)) to commercial mesh size (139 mm)	3.6–4.2	4.3–4.8	4.9–5.6	Scoring thresholds based on Roux et al. [30]

(140 mm). A higher ratio (larger mean fish length) is taken to indicate higher potential for the gear to capture and retain fish, and thus higher susceptibility. Ratio tiers defined in Roux et al. [30] were used to score selectivity. Data quality for susceptibility attributes was deemed comparable among stocks and was not investigated further in this analysis.

2.3.3. FK attributes

FK data were used to estimate a set of FK attributes for use in productivity-susceptibility analysis. These included one attribute related to stock productivity (FK-Fish size) and six attributes related to fishery susceptibility: FK-Overlap, FK-Catchability, FK-Seasonality, FK-Subsistence Harvest, FK-Effort and FK-Desirability (Table 5). Some FK attributes (e.g., FK-Effort and FK-Fish size) were scored directly from the answers to the scoring questions in the interview questionnaire. FK-Overlap was scored based on preferred fishing locations identified on maps, using the same scoring thresholds as the “Availability” susceptibility attribute (Section 2.3.2., Table 4). FK-Catchability expresses quality of fishing for a stock, as averaged across seasons (since fishers were asked to score each stock for quality of fishing by season). FK-Seasonality relates to the recurrence (intensity) of fishing within a year, as determined based on distance and environmental factors affecting seasonal accessibility (i.e., presence/absence of ice sheets and snow facilitating or hampering travel). Stocks fished during both the open-water seasons (summer and autumn) and ice-cover seasons (winter and spring) are accessible year-round and thus susceptible to higher fishing pressure. For the FK-Subsistence Harvest attribute, there was a tendency for fishers to only identify stocks that have (or traditionally have had) a high importance as a source of food to the community (as opposed to scoring individual stocks). In such cases, stocks identified as important locations for subsistence harvests were given a score of 3 (= high levels of subsistence harvest) and all other stocks were given a score of 1 (= low levels of subsistence harvest). Similarly, for the FK-Desirability attribute, fishers tended to only identify their favourite and least favourite fish/waterbody (as opposed to scoring individual stocks). In this case, waterbodies identified as “favourite fish” were given a score of 3 (= high desirability), while those identified as least favourite were given a score of 1 (= low desirability). All other stocks were given a score of 2 (desirable fish).

For each FK attribute, individual fisher scores were combined using weighted average, whereby each fisher's score was weighted based on the fisher's number of years of experience fishing in the Cumberland Sound Area. Fishers with over 20 years of experience were given a weight of 1 on all their scores. Those having between 10 and 20 years of experience were given a weight of 0.8; a weight of 0.5 was used for fishers having between 5 and 10 years of experience; and a weight of 0.2 was applied to all scores from fishers having less than 5 years of experience. This resulted in continuous scores for FK attributes within the range [1,3].

2.3.4. Productivity-susceptibility analysis with FK

The PSA framework allows for direct and indirect inclusion of FK information. Direct inclusion was performed by estimating susceptibility for each stock based on FK susceptibility attributes (Table 5). Indirect inclusion was performed by weighting the productivity attribute L_{MAX} based on similar information in the FK data (FK-Fish size). L_{MAX} scores were up-weighted (weight = 1.5) if convergence between biological and FK data was observed, and down-weighted (weight = 0.5) where biological and FK information diverged. Three separate PSA assessments were performed: a standard estimation (PSA conducted without FK); and two PSAs with FK, including FK-weighted productivity scores and susceptibility scores estimated using FK susceptibility attributes (PSA with FK susceptibility) or a combination of standard and FK susceptibility attributes (combined PSA). The overall productivity score for each stock was obtained by averaging across weighted productivity attributes. An even weight (= 1.0) was assumed for L_{MAX}, A_{MAX}, $A_{RECRUIT}$ and Z in the standard PSA estimation, or L_{MAX} was weighted based on FK information (in PSAs with FK). L_{A10} was given a lower weight (= 0.5) in all scenarios since this attribute consistently scored low (DQ = 5) on the data quality index (Table 3). Susceptibility was estimated as the product of encounterability, availability and selectivity (standard estimation); as the product of FK-Overlap, FK-Catchability, FK-Seasonality, FK-Desirability, FK-Effort and FK-Subsistence Harvest (PSA with FK susceptibility); or as the product of FK susceptibility attributes and the standard encounterability and selectivity attributes (combined PSA). Susceptibility scores were then rescaled to the [1,3] interval. In both standard and FK estimations, susceptibility attributes were given a similar, relative importance in determining exposure to fishing activities (i.e., all attributes were given a weight of 1).

For each stock, productivity and susceptibility scores (and FK-weighted Productivity and FK-Susceptibility or combined FK/standard susceptibility scores) were plotted on a two-dimensional productivity-susceptibility plot, with circles size determined based on the data quality index for productivity attributes (larger circles corresponding to greater uncertainty). Higher risk corresponds to stocks with lower productivity and higher susceptibility scores and vice-versa. Higher risk stocks are considered most vulnerable to fishing activities (i.e., less likely to withstand increased mortality caused by fishing and support sustainable fisheries).

3. Results

Results of PSA assessments conducted with and without the inclusion of FK data are summarised in Table 6. For each stock, productivity and susceptibility scores were plotted by assessment scenario (standard PSA and PSAs with FK) on the two-dimensional productivity-susceptibility plot (Fig. 2). The PSA method was able to distinguish relative risk from fishing activities among Arctic char stocks in the Cumberland Sound Area. The three assessment scenarios identified Nauliniavik (PG008) as the stock being at higher risk from fishing activities and Qasigiyat (PG015) as a lower risk stock. These results are consistent with these stocks having lowest (1.2) and highest (2.7) productivity scores, respectively (Table 6). Productivity scores adjusted for correspondence with FK data (P (FK wt)) were slightly lower (−0.1) in three

Table 5
Fishers knowledge (FK) attributes considered for productivity-susceptibility analysis, including six FK-susceptibility attributes and scoring thresholds and one FK-productivity attribute (FK- Fish size) and productivity tiers.

	Description	Low (1)	Moderate (2)	High (3)
FK-Susceptibility attributes				
FK-Overlap	Overlap between preferred fishing location(s) and habitat type (as a surrogate for species incidence and distribution)	Ocean (coastal areas)	Lakes and/or fjords (or coastal areas and river mouth combination)	River mouth
FK-Catchability	Quality of fishing averaged across seasons	Poor fishing	Good fishing	Very good fishing
FK-Seasonality	Annual recurrence of fishing as related to seasonal accessibility.	Fished once a year during either the ice-cover or open-water season	Fished more than once a year during either the open-water (summer and autumn) or ice-cover (winter and spring) season.	Fished during both the open-water and ice-cover seasons (accessible year-round).
FK-Effort	Effort required to catch fish	Important effort required (not so easy to catch fish)	Usual effort required (relatively easy to catch fish)	Little effort required (very easy to catch fish)
FK-Subsistence Harvest Levels	Relative importance as a food fishery to the community	Low	Moderate	High
FK-Desirability	Fish/waterbody preference and desirability as determined based on taste and quality of the flesh, parasite loading, and other criteria.	Not so desirable (least favourite) fish	Desirable fish	Highly desirable (favourite) fish
FK-Productivity Attribute				
FK-Size	Average fish size (relative to other stocks in the study area)	large fish	average size fish	small fish

stocks (PG008, PG080 and PG015), higher (+ 0.1) in one stock (PG014), and remained unchanged in other stocks, overall indicating good agreement between empirical biological data and FK information. Data quality scores were highest in PG008, high in PG014 and generally comparable among other stocks. Higher data quality scores indicate greater uncertainty in the available biological data used to estimate productivity attributes.

Important differences in stock susceptibility to fishing activities were observed with the inclusion of FK data. Susceptibility scores estimated using FK attributes, or the combination of standard and FK attributes, were substantially reduced in two stocks (Nauliniavik PG008 and Iqaluit PG001) and markedly increased in one stock (Kingnait PG014). Other, less important increases in susceptibility scores were observed in two waterbodies (Isuituq PG080 and Kipisa PG004). Susceptibility for Qasigiyat (PG015) was low (= 1) in all assessment scenarios and insensitive to the inclusion of FK.

In the case of Nauliniavik (PG008), the reduction in susceptibility with the inclusion of FK was linked to this stock scoring lowest (= 1) in terms of subsistence harvests (FK-Subsistence Harvest attribute) (Table 7). Lower susceptibility reduced the overall risk score for the stock (from 2.7 in the standard PSA to 2.1 and 2.2 in PSAs with FK), but did not affect its overall risk ranking (highest risk in all scenarios). In the case of Iqaluit (PG001), reduced susceptibility with the inclusion of FK was related to a lower overlap between preferred fishing locations and Arctic char habitat in the FK data (attribute score for FK-Overlap = 1.5) (Table 7). The inclusion of FK lowered the overall risk and risk ranking for the stock, from second highest (in standard PSA) to third place (in PSAs with FK). In Kingnait (PG014), increased susceptibility with FK inclusion was linked to this stock scoring highest in terms of annual quality of fishing (FK-Catchability), desirability (FK-Desirability) and subsistence harvest levels (FK Subsistence Harvest) (Table 7). The inclusion of FK data substantially increased risk estimates (from 1.4 to 2.1) and risk rankings for the stock (from third to second highest and even highest risk (with PG008) in the FK Risk scenario). Other stocks (PG004 and PG080) showed comparable, limited increases in overall risk scores in PSAs with FK. The increase in susceptibility for Kipisa (PG004) in the FK Risk scenario was sufficient to rank the stock in second place (i.e., higher risk behind PG008 and PG014).

4. Discussion

Alternative approaches are required that can augment the information on which to base small-scale, data-limited fisheries management. In Canada's Arctic region, the assessment and management of small-scale fisheries for Arctic char remain complicated by data paucity, incomplete harvest statistics, by the large number and widespread distribution of stocks over a vast and remote territory, and a changing climate likely affecting stocks productivity and resilience to fishing activities. For all these reasons, conventional scientific assessments with high data requirements are neither applicable nor effective to ensure fishery sustainability. Arctic char resources have high value for food security, cultural identity and local economic development in Arctic communities. Traditional ecological fishers knowledge on Arctic char populations is available where scientific observations are scarce, incomplete, or inexistent. This calls for the incorporation of FK in stock status and management strategies evaluation for the species in Arctic regions. The relevance of FK for small-scale fisheries management has been demonstrated [5,25,26], yet the tools and guidance required to integrate FK and scientific expertise in fisheries assessments remain elusive.

The productivity-susceptibility analysis provides a flexible tool for the incorporation of alternative information sources and the evaluation of risk from fishing activities. Single-species applications are uncommon but feasible for Arctic char owing to important life history diversity among populations, which ensures persistence in extreme and

Table 6
Results of productivity-susceptibility analyses (PSA) for six anadromous Arctic char stocks in the Cumberland Sound Area, Nunavut, including stock-specific productivity (P) and susceptibility (S) scores; data quality scores (DQ) (for productivity attributes); and risk scores and ranking (1 = higher risk) estimated in PSA assessments including FK data (FK Risk and Combined Risk) and not including FK data (Standard Risk). FK Risk was estimated using FK-weighed productivity scores (P (FK wt)) and susceptibility scores estimated using FK susceptibility attributes (S (FK)). Combined Risk was estimated using P (FK wt) and susceptibility scores calculated using both standard and FK susceptibility attributes (S (combined)). Stocks are ranked from highest to lowest risk as estimated in the Combined Risk assessment scenario.

Stock/waterbody		Productivity (P)			Susceptibility (S)			Standard risk		FK risk		Combined risk	
Code	Name	P	P (FK wt)	DQ	S	S (FK)	S (combined)	Score	Rank	Score	Rank	Score	Rank
PG008	Nauliniavik	1.2	1.1	3.8	3.0	1.8	2.2	2.7	1	2.1	1	2.2	1
PG014	Kingnait	2.2	2.3	3.2	2.1	3.0	3.0	1.4	3	2.1	1	2.1	2
PG001	Iqaluit	2.0	2.0	2.2	3.0	1.8	2.2	2.2	2	1.3	3	1.6	3
PG004	Kipisa	1.9	1.9	2.0	1.5	1.9	1.7	1.2	4	1.4	2	1.3	4
PG080	Isuituq	2.2	2.1	2.0	1.0	1.6	1.5	0.8	5	1.1	4	1.0	5
PG015	Qasigiyat	2.7	2.6	2.2	1.0	1.0	1.0	0.3	6	0.4	5	0.4	6

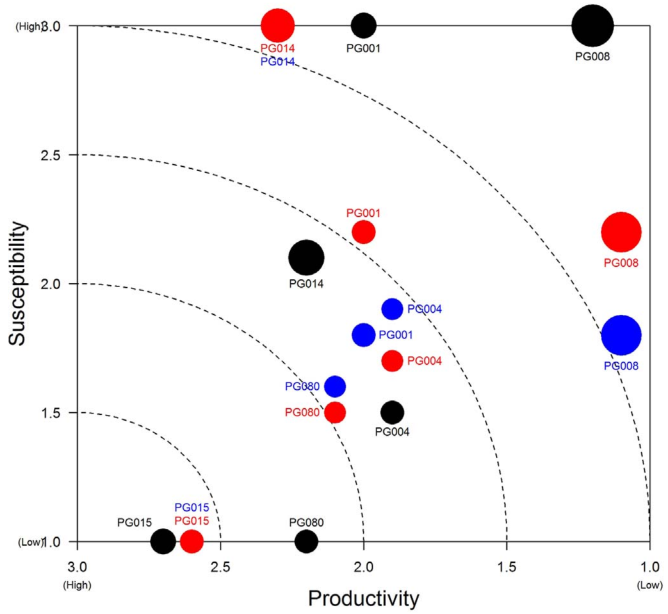

Fig. 2. Productivity-susceptibility plot for six Arctic Char stocks from the Cumberland Sound Area, Nunavut, Canada. Black circles: productivity-susceptibility analysis conducted without fishers knowledge (FK); Blue circles: productivity-susceptibility analysis incorporating FK (FK-susceptibility attributes and FK-weighed productivity); Red circles: productivity-susceptibility analysis with FK integration (combined FK/standard susceptibility attributes and FK-weighed productivity). Circles size is proportional to data quality scores (i.e., larger circles indicate greater uncertainty). Stocks/waterbody codes and names are given in Table 6. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

unpredictable Arctic aquatic environments [41,45,46]. PSA assessments performed with and without the incorporation of FK allowed to distinguish and rank the relative risk from fishing activities among Arctic char stocks within the Cumberland Sound Area. This again illustrates the utility of the approach for distinguishing between stocks that are more or less vulnerable to fishing activities on a regional basis [30]. The inclusion of FK served to enhance susceptibility evaluation (direct inclusion) and validate the available biological data (indirect inclusion). In our case study example, a single FK productivity attribute (fish size) was used to assess correspondence (and down or up-weight) biological data in productivity evaluation. The possibility exists however, to seek additional FK insights on the productivity traits of fish populations for use in PSA assessment (e.g., growth, spawning stock biomass, time series of relative abundance, etc.). Information on fish condition, parasite loads, timing of migrations and shifts in size distribution, was often provided in the comments sections of the interview questionnaire, but not collected in a systematic way among fishers. This information is highly valuable to the assessment of stock productivity. Improved FK data collection would assist with broadening the scope of FK that can be incorporated and integrated with scientific data in the PSA framework, and provide more reliable estimates of stock productivity. Where biological sampling is limited, sporadic and/or outdated, improved and continuous FK documentation (and correspondence evaluation between FK and available biological data within PSA assessments), may assist with detecting changes in stock productivity linked to climate drivers or other factors.

The inclusion of FK enhanced fisheries exposure and fishing intensity estimation for Arctic char stocks in the study area. FK attributes such as overlap, catchability, seasonality and effort, provided factual and experiential information on the overlap between fishing effort and stocks distribution, seasonal accessibility, quality of fishing and effort intensity. This information served to more reliably index stocks susceptibility to fishing, in comparison with the standard approach based on availability, encounterability and selectivity proxies. Overlap inferred based on FK information (preferred fishing locations identified on maps) was considered more reliable and representative than the standard availability attribute inferred based on sampling locations in the survey data. For this reason, FK-Overlap scores were retained (and standard availability scores excluded) in the combined susceptibility assessment (combined PSA). Other FK attributes like desirability and subsistence harvest permitted to account for the relative importance of food fisheries. The lack of reliable quantitative information on subsistence harvests is a continued problem for stock assessments of Arctic

Table 7
Standard and FK susceptibility attributes scores among stocks.

Stock	Standard susceptibility attributes			FK susceptibility attributes					
	Encounterability	Availability	Selectivity	FK-Overlap	FK-Catchability	FK-Seasonality	FK-Effort	FK-Desirability	FK-Subsistence Harvest
PG001	1.7	2	2	1.5	2.4	2.2	2.3	2.5	2
PG004	1.9	2	1	1.9	2.8	1.9	2.2	2.2	2
PG008	1.7	2	2	2.1	2.9	2.1	3	2.3	1
PG014	2.5	2	1	2.1	3	1.9	2.8	2.7	2.2
PG015	1.4	2	1	1.7	2.4	1.3	1.8	2.1	1.2
PG080	1.9	1.5	1	2.5	2.6	1.4	2.5	2.2	1.5

char. In recent decades, subsistence harvest levels have fluctuated with changing lifestyles, demographics and local economies [47,48]. More recently, changes in Arctic char flesh (taste and appearance) linked to trophic shifts in Arctic marine ecosystems have been documented in Arctic regions including the Cumberland Sound Area [49]. This and other factors like changes in parasite loads were identified as rationales for scoring fisheries for desirability during fishers interviews. These changes are likely to affect subsistence catch levels among stocks on a regional basis. Variations in subsistence catches coupled with commercial harvests, can substantially increase or decrease fishing pressure for a stock. The inclusion of FK subsistence harvest and fishery desirability attributes improved the evaluation of current fishing intensity (and thus, susceptibility) in PSA assessments.

Higher susceptibility with the inclusion of FK in Kingnait (PG014) Arctic char, is in agreement with recent observations and management initiatives for this stock [50]. In contrast, standard PSA performed without FK, failed to recognise the importance of Kingnait Arctic char as a preferred, convenient and highly desirable food fishery for the community. Conversely, the inclusion of FK information permitted to account for the low significance of Nauliniavik (PG008) Arctic char as a source of food for the community. Reduced susceptibility with the inclusion of FK in Nauliniavik (PG008), is consistent with this stock being far away from the community and least accessible (since its location near the mouth of Cumberland Sound requires long-distance travel on land, as opposed to faster travel on ice), making it impractical to fish without additional economic (i.e., commercial) incentives.

Without FK inclusion, the PSA assessment over-estimated the risk from fisheries to two Arctic char stocks (Nauliniavik and Iqaluit) and under-estimated risk in one stock (Kingnait), and to a lesser extent in two others (Kipisa and Isuituq stocks). PSA assessments conducted with FK identified Nauliniavik and Kingnait as higher risk stocks (based on low productivity and high susceptibility, respectively), and Qasigiyat as a lower risk stock. Based on these results, preliminary advice for management may consist of identifying and prioritising both Kingnait and Nauliviavik as potentially the least sustainable fisheries in the Cumberland Sound Area. Similar advice derived from PSA assessment with no FK information, would instead prioritise Nauliniavik and Iqaluit as least sustainable fisheries. This illustrates the potential impacts of ignoring FK on the assessment results and ensuing advice for management. Direct outputs comparison represents an improvement over studies in which FK and scientific perspectives are considered side by side, and FK is only included to validate or invalidate scientific results or information [2,6,18]. The PSA approach allowed for direct and indirect incorporation of FK in a semi-quantitative fisheries risk assessment process, with opportunities for participative engagement and collaboration at the data acquisition, advice formulation, and management decision-making steps.

We note that a fully integrated assessment would require the combination of science and FK data on equal terms. In our case study application, empirical biological data still outweighed FK in the definition and scoring of stocks productivity attributes, while FK outweighed scientific information in the assessment and scoring of stocks susceptibility (in the combined PSA scenario). The PSA framework is flexible and can be easily adapted to integrate FK and science information as data are augmented. Key to achieving integration however, is the 'bridge building' process that underlies partnerships development, information sharing, FK documentation, biological samples collection, and management decision making. This process requires fishers, community stakeholders, fisheries and social scientists, as well as natural resources managers, to be involved at the study design stage. In the case of Cumberland Sound Arctic char, 'bridge building' was facilitated by long-term research initiatives and collaborations between fishers, community stakeholders and government scientists, which began in the mid-1990s. Initially focused on data acquisition and field sampling, such collaborations have now expanded to encompass FK documentation and inclusion in fisheries assessments, as well as the development of a community-based fishery monitoring programme. Thus, while the FK sample used in our case study can be seen as incomplete or imperfect, the foundation is there to enhance and refine FK data acquisition and implement iterative, fully integrated PSAs in the future.

Within a regional management framework, results of PSA assessments can be used as a first step in providing information on which to prioritise monitoring and sampling initiatives, review and compare total allowable catch (TACs) among stocks, and implement adaptive management actions. High risk scores may serve as a trigger for revising and setting more precautionary TACs, either for higher risk stocks at the regional scale, or for regions comprising a large number of high risk stocks over a broad spatial scale. Higher risk stocks (e.g., Nauliviavik (PG008) and Kingnait (PG014)), may serve as candidate indicator populations for monitoring the impacts of small-scale commercial and subsistence fisheries. Focusing sampling and monitoring effort on high risk stocks provides a precautionary means of minimising the investment required to ensure sustainable management and conservation at the regional scale [30]. Alternatively, stocks identified as being at lower risk (e.g., Qasigiyat (PG015)), may serve as targets for adaptive management actions such as experimental test fisheries with progressive harvest increase (or contrasting exploitation rates) [51]. The information collected under adaptive management scenarios will assist with quantifying the responses of fish stocks to fishing mortality, and assist with the design of more complex numerical simulations permitting to explore and evaluate the outcomes of alternative management scenarios [52].

Within our case study, FK was documented in semi-directed interviews involving a total of 16 community fishers whose experience with Cumberland Sound Arctic char fisheries ranged from 2 to 60 years. The inclusion of FK served to augment the reliability and certainty of PSA outcomes. Hence, both FK and scientific observations have uncertainties of their own, but combining them can reduce overall uncertainty [15]. We note that proper assessment of uncertainty was not performed in this study, but would represent a highly valuable next step. Uncertainty evaluation was here limited to the formulation of a data quality index and scoring of productivity attributes for data quality, which served to appraise uncertainty in the available biological data. Uncertainty in FK information was bounded by weighting individual fishers scores based on years of experience in the calculation of FK attributes scores, but was neither assessed nor propagated throughout the assessment framework. Phillips [38] proposed a method for modelling uncertainty in expert responses to susceptibility attributes within the PSA framework. This method might be applicable and useful to quantify uncertainty in fishers responses and associated FK attributes in combined PSA assessment. Within our case study, the concise format of the interview questionnaire and the scoring questions were key to minimising subjectivities and facilitating the translation of FK information on an ordinal scale for inclusion in PSA assessment. Yet not all respondents were able to contribute knowledge on each of the six stocks considered for assessment, resulting in different sample sizes among FK attributes and variable uncertainty. Moreover, and as indicated in the methods Section 2.3.3, there were instances in which the scoring approach failed because fishers only identified the most/least important/desirable stocks as opposed to scoring them individually. This required adjustments to be performed for incorporation into PSA, with potential bias introduction. Another source of potential bias or subjectivity was through the language barrier, including the use of translated questionnaires and the fact that semi-directed interviews were conducted in collaboration with different translators. Proper evaluation and characterisation of uncertainty in FK information, would assist with the appraisal of PSA outcomes in relation to uncertainty in both productivity and FK attributes. It would also assist with identifying sources of uncertainty in the data acquisition process, and formulate recommendations for improving interview questionnaires or other FK documentation methods.

The need for FK integration in small-scale fisheries assessments and

management systems, challenges scientists and managers to re-examine their own assumptions, intellectual filters, ontologies and paradigms [4]. Within the PSA framework, direct and indirect incorporation of FK can serve to broaden the scope of the information available for assessment, validate one set of observations relative to the other, and provide more reliable, semi-quantitative estimates of risk. The method is flexible, relevant and applicable to other small-scale, data-limited fisheries. PSA with FK can be performed on multi-species and single-species fisheries, locally-adapted to fit existing biological, FK and fishery exposure information, and further expanded to incorporate economic attributes in susceptibility estimation. Even in the absence of broad diversity in stocks productivity, PSA with FK can provide sufficient contrast for ranking stocks based on differential fishery susceptibility. The embedded process of productivity evaluation and validation based on FK information, can provide a simple means of monitoring changes in stock productivity, in cases where FK documentation can be easily repeated and is practical in comparison with biological sampling. The development and implementation of community-based fisheries monitoring programmes, will facilitate routine FK documentation and integration in fisheries assessments, and extend opportunities for participative engagement of community harvesters and stakeholders in the formulation of integrated science/FK advice for fisheries management.

5. Conclusions

One way to enhance the sustainable management of small-scale, data-limited fisheries, is to develop alternative approaches that can incorporate fishers knowledge information in scientific stock assessments. The productivity-susceptibility analysis offers a flexible framework for including FK in the evaluation of risk from fishing activities to fish stocks and fishery sustainability. PSA outputs can be used to define triggers for TACs adjustments, prioritise high risk stocks for sampling and monitoring, and identify fishery sectors suitable for adaptive management actions. The method has direct implications in the formulation of science advice for management and can inform management decision-making within relevant timeframes. It can also serve as a first step in the design of feedback control strategies or data-limited management strategy evaluation. We demonstrated the practicalities and usefulness of the approach as applied to small-scale Arctic char fisheries in an area subset of the vast Canadian Arctic. Our case study example illustrates a simple method for FK data collection, direct and indirect inclusion of FK in PSA assessments, and the potential impacts of ignoring FK on assessment outcomes and ensuing management advice. Recommendations were made to refine the method in future iterations, including enhancement of FK data acquisition and uncertainty evaluation. The PSA approach with FK is applicable and recommended for improved management of other small-scale fisheries, especially where fishers knowledge is available where scientific observations are scarce, incomplete or inexistent.

Acknowledgments

This study was co-funded by the Nunavut Wildlife Management Board, Government of Nunavut and Government of Canada Department of Fisheries and Oceans (DFO). The authors wish to thank the Pangnirtung hamlet, community harvesters and Hunters and Trappers association (HTA), for research support and assistance with project coordination and contributions to the process of FK data acquisition. We also wish to acknowledge the Kivalliq Wildlife Board for supporting this research, as well as several DFO staff members, contributors and community collaborators involved in data collection, laboratory (fish aging) analyses and stock assessments of Arctic char in Nunavut and the Northwest Territories since the 1970s. D. Bowden contributed GIS skills and maps. We thank two anonymous reviewers for useful comments and suggestions. This paper is dedicated to the memory of Mr. Chris Day.

References

[1] P.J. Usher, Traditional ecological knowledge in environmental assessment and management, Arctic (2000) 183–193.
[2] H.P. Huntington, Using traditional ecological knowledge in science: methods and applications, Ecol. Appl. 10 (5) (2000) 1270–1274.
[3] V.M. Trenkel, S.B. Kraak, J. Rice, M.-J. Rochet, A.D. Smith, Introduction to some alternative methods for providing scientific information for management, in: C.T.T. Edwards, D.J. Dankel (Eds.), Management Science in Fisheries: An Introduction to Simulation-based Methods, Routledge, New York, 2016, pp. 375–392.
[4] D. Smith, M. Woodrow, K. Vodden, A boat perspective: local geographic knowledge of fish harvesters in Change Islands, Newfoundland, J. Cult. Geogr. 33 (1) (2016) 1–26.
[5] C.S. Seixas, M.A. Veira, Fisher's knowledge and the ecosystem approach to fisheries: legal instruments and lessons from five cases studies in coastal Brazil, in: J. Fischer, J. Jorgensen, H. Josupeit, D. Kalikoski, C.M. Lucas (Eds.), Fishers' Knowledge and the Ecosystem Approach to Fisheries, FAO Fisheries and Aquaculture Technical Paper, 2015, p. 278.
[6] J. York, M. Dowsley, A. Cornwell, M. Kuc, M. Taylor, Demographic and traditional knowledge perspectives on the current status of Canadian polar bear subpopulations, Ecol. Evol. 6 (9) (2016) 2897–2924.
[7] T. Pearce, J. Ford, A.C. Willox, B. Smit, Inuit traditional ecological knowledge (TEK), subsistence hunting and adaptation to climate change in the Canadian Arctic, Arctic 68 (2) (2015) 233–245.
[8] N. Houde, The six faces of traditional ecological knowledge: challenges and opportunities for Canadian co-management arrangements, Ecol. Soc. 12 (2) (2007) 17.
[9] G.W. Wenzel, From TEK to IQ: Inuit Qaujimajatuqangit and Inuit cultural ecology, Arct. Anthropol. 41 (2) (2004) 238–250.
[10] B. Ayles, L. Porta, R.M. Clarke, Development of an integrated fisheries co-management framework for new and emerging commercial fisheries in the Canadian Beaufort Sea, Mar. Policy (2016) 246–254.
[11] D. Gondor, Inuit knowledge and environmental assessment in Nunavut, Canada, Sustain. Sci. 11 (1) (2016) 153–162.
[12] G. Gilchrist, M. Mallory, F. Merkel, Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds, Ecol. Soc. 10 (1) (2005) 12.
[13] M.L. Mallory, H.G. Gilchrist, A.J. Fontaine, J.A. Akearok, Local ecological knowledge of ivory gull declines in Arctic Canada, Arctic (2003) 293–298.
[14] K. Marin, A. Coon, D. Fraser, Traditional ecological knowledge reveals the extent of sympatric lake trout diversity and habitat preferences, Ecol. Soc. 22 (2) (2017) 11.
[15] H.P. Huntington, R.S. Suydam, D.H. Rosenberg, Traditional knowledge and satellite tracking as complementary approaches to ecological understanding, Environ. Conserv. 31 (03) (2004) 177–180.
[16] A. Lewis, M. Hammill, M. Power, D. Doidge, V. Lesage, Movement and aggregation of eastern Hudson Bay beluga whales (Delphinapterus leucas): a comparison of patterns found through satellite telemetry and Nunavik traditional ecological knowledge, Arctic (2009) 13–24.
[17] C. Furgal, R. Laing, A synthesis and critical review of the traditional ecological knowledge literature on Narwhal (Monodon monoceros) in the Eastern Canadian Arctic., Canadian Science Advisory Secretariat, Ottawa (2012) (iv + 47).
[18] L.M. Martinez-Levasseur, C.M. Furgal, M.O. Hammill, G. Burness, Towards a better understanding of the effects of UV on Atlantic Walruses, Odobenus rosmarus rosmarus: a study combining histological data with local ecological knowledge, PLOS One 11 (4) (2016) e0152122.
[19] G. Noongwook, H.P. Huntington, J.C. George, Traditional knowledge of the bowhead whale (Balaena mysticetus) around St. Lawrence Island, Alaska, Arctic (2007) 47–54.
[20] J.Å. Riseth, H. Tømmervik, E. Helander-Renvall, N. Labba, C. Johansson, E. Malnes, J.W. Bjerke, C. Jonsson, V. Pohjola, L.-E. Sarri, Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change, Polar Rec. 47 (03) (2011) 202–217.
[21] E. Weatherhead, S. Gearheard, R. Barry, Changes in weather persistence: insight from Inuit knowledge, Glob. Environ. Change 20 (3) (2010) 523–528.
[22] H. Huntington, T. Callaghan, S. Fox, I. Krupnik, Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems, AMBIO (2004) 18–23.
[23] H.P. Huntington, "We dance around in a ring and suppose": academic engagement with traditional knowledge, Arct. Anthropol. 42 (1) (2005) 29–32.
[24] F. Berkes, J. Colding, C. Folke, Rediscovery of traditional ecological knowledge as adaptive management, Ecol. Appl. 10 (5) (2000) 1251–1262.
[25] E.J. Hind, A review of the past, the present, and the future of fishers' knowledge research: a challenge to established fisheries science, ICES J. Mar. Sci.: J. Cons. (2014) 341–358.
[26] R.E. Johannes, M.M. Freeman, R.J. Hamilton, Ignore fishers' knowledge and miss the boat, Fish Fish. 1 (3) (2000) 257–271.
[27] A. Balikci, Charr Fishing among the Arviligjuarmiut Charrs: Salmonid Fishes of the Genus Salvelinus, Dr. W. Junk Publishers, The Hague, 1980, pp. 7–9.
[28] L. Johnson, Charr and man: the philosophy of limited interactions, Biology of the Arctic charr: in: Proceedings of the International Symposium on Arctic charr., University of Manitoba Press, Winnipeg, Manitoba, 1984, pp. 523–532.
[29] H. Priest, P.J. Usher, The Nunavut Wildlife Harvest Study, August 2004: Final Report, Nunavut Wildlife Management Board, Nunavumi Umayuligiyit Katimayiit, 2004, p. 822.
[30] M. Roux, R. Tallman, C. Lewis, Small-scale Arctic charr Salvelinus alpinus fisheries in Canada's Nunavut: management challenges and options, J. Fish. Biol. 79 (6)

(2011) 1625–1647.
[31] D.A. Milton, Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery, Biol. Conserv. 101 (3) (2001) 281–290.
[32] I.C. Stobutzki, M.J. Miller, D.S. Heales, D.T. Brewer, Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery, Fish. Bull. 100 (4) (2002) 800–821.
[33] A. Smith, E. Fulton, A. Hobday, D. Smith, P. Shoulder, Scientific tools to support the practical implementation of ecosystem-based fisheries management, ICES J. Mar. Sci.: J. Cons. 64 (4) (2007) 633–639.
[34] W.S. Patrick, P. Spencer, J. Link, J. Cope, J. Field, D. Kobayashi, P. Lawson, T. Gedamke, E. Cortes, O. Ormseth, Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing, Fish. Bull. 108 (3) (2010) 305–322.
[35] E. Cortés, F. Arocha, L. Beerkircher, F. Carvalho, A. Domingo, M. Heupel, H. Holtzhausen, M.N. Santos, M. Ribera, C. Simpfendorfer, Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries, Aquat. Living Resour. 23 (1) (2010) 25–34.
[36] H. Arrizabalaga, P. De Bruyn, G.A. Diaz, H. Murua, P. Chavance, A.D. de Molina, D. Gaertner, J. Ariz, J. Ruiz, L.T. Kell, Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries, Aquat. Living Resour. 24 (1) (2011) 1–12.
[37] L. Dransfeld, H.D. Gerritsen, N.R. Hareide, P. Lorance, Assessing the risk of vulnerable species exposure to deepwater trawl fisheries: the case of orange roughy Hoplostethus atlanticus to the west of Ireland and Britain, Aquat. Living Resour. 26 (4) (2013) 307–318.
[38] S.R.M. Phillips, F. Scott, J.R. Ellis, Having confidence in productivity susceptibility analyses: a method for underpinning scientific advice on skate stocks? Fish. Res. 171 (2015) 87–100.
[39] A.E. Aitken, R. Gilbert, Holocene nearshore environments and sea-level history in Pangnirtung Fiord, Baffin Island, NWT, Canada, Arct. Alp. Res. (1989) 34–44.
[40] Q.I. Association, Qikiqtani Truth Commission: Community Histories 1950–1975. Pangnirtung. 2013, 2016(〈http://www.qtcommission.ca/sites/default/files/community/community_histories_pangnirtung.pdf〉.
[41] L. Johnson, The arctic charr, Salvelinus alpinus, in: E.K. Balon (Ed.), Charrs: Salmonid Fishes of the Genus Salvelinus, Dr. W. Junk Publishers, The Hague, Netherlands, 1980, pp. 15–98.
[42] H.P. Huntington, Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge, Arctic (1998) 237–242.
[43] T. Loewen, D. Gillis, R. Tallman, Ecological niche specialization inferred from morphological variation and otolith strontium of Arctic charr Salvelinus alpinus L. found within open lake systems of southern Baffin Island, Nunavut, Canada, J. Fish Biol. 75 (6) (2009) 1473–1495.
[44] S.C. Stearns, The Evolution of Life Histories, Oxford University Press, Oxford, Oxford, UK, 1992.
[45] A. Klemetsen, P.A. Amundsen, J. Dempson, B. Jonsson, N. Jonsson, M. O′connell, E. Mortensen, Atlantic salmon Salmo salar L., brown trout Salmo trutta L. and Arctic charr Salvelinus alpinus (L.): a review of aspects of their life histories, Ecol. Freshw. Fish 12 (1) (2003) 1–59.
[46] M. Power, J.D. Reist, J.B. Dempson, Fish in high-latitude Arctic lakes, in: W.F. Vincent, J. Laybourn-Parry (Eds.), Polar Lakes and Rivers, Limnology of Arctic and Antarctic Aquatic Ecosystems, 2008, pp. 249–267.
[47] P. Collings, G. Wenzel, R.G. Condon, Modern food sharing networks and community integration in the central Canadian Arctic, Arctic (1998) 301–314.
[48] D. Zeller, S. Booth, E. Pakhomov, W. Swartz, D. Pauly, Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems, Polar Biol. 34 (7) (2011) 955–973.
[49] K.L. Ulrich, Trophic Ecology of Arctic char (Salvelinus alpinus L.) in the Cumberland Sound region of the Canadian Arctic, University of Manitoba, Winnipeg, Manitoba, Canada, 2013.
[50] DFO, Assessing the impact of harvest on Kingnait Fjord Arctic char in the Cumberland sound area of Baffin Island, DFO Can. Sci. Advis. Sec. Sci. Rep. (2009) (2009/013).
[51] C.J. Walters, R. Hilborn, Adaptive control of fishing systems, J. Fish. Board Can. 33 (1) (1976) 145–159.
[52] C.T. Edwards, D.J. Dankel, Management Science in Fisheries: An Introduction to Simulation-based Methods, Routledge, New York, 2016.